

# A LightGBM-Based Analysis of Academic Resilience Among Gifted Students with Twice-Exceptional Profiles: Contributions of Metacognitive Awareness, Emotional Regulation, and Perceived Teacher Support

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### Article Info

#### Article type:

*Original Research*

#### How to cite this article:

Al-Kuwari, F., & Cartwright, E. (2026). A LightGBM-Based Analysis of Academic Resilience Among Gifted Students with Twice-Exceptional Profiles: Contributions of Metacognitive Awareness, Emotional Regulation, and Perceived Teacher Support. *Psychological Research in Individuals with Exceptional Needs*, 4(1), 1-13.

<https://doi.org/10.61838/kman.prien.5678>



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### ABSTRACT

The present study aimed to examine the predictive contributions of metacognitive awareness, emotional regulation, and perceived teacher support to academic resilience among gifted students with twice-exceptional profiles using a Light Gradient Boosting Machine (LightGBM) model. This cross-sectional predictive study was conducted among 428 gifted students with documented twice-exceptional profiles recruited from educational institutions across Canada. Participants completed standardized measures assessing academic resilience, metacognitive awareness, emotional regulation, and perceived teacher support. Preliminary statistical analyses included descriptive statistics and Pearson correlation coefficients. Subsequently, a LightGBM machine learning model was developed to predict academic resilience. The dataset was divided into training (80%) and testing (20%) subsets, and model performance was evaluated using the coefficient of determination ( $R^2$ ), root mean square error (RMSE), mean absolute error (MAE), and mean absolute percentage error (MAPE). Feature importance and SHAP (Shapley Additive Explanations) analyses were performed to determine the relative contributions of the predictor variables. Inferential analyses revealed significant positive correlations between academic resilience and metacognitive awareness ( $r = .71, p < .01$ ), perceived teacher support ( $r = .63, p < .01$ ), and emotional regulation ( $r = .58, p < .01$ ). The LightGBM model demonstrated excellent predictive performance, explaining 84.7% of the variance in academic resilience within the testing dataset ( $R^2 = .847$ ), with low prediction error values (RMSE = 6.84, MAE = 5.18, MAPE = 5.03%). Feature importance analysis indicated that metacognitive awareness was the strongest predictor of academic resilience (43.82%), followed by perceived teacher support (33.76%) and emotional regulation (22.42%). SHAP analyses confirmed these findings, revealing that metacognitive awareness exerted the greatest influence on resilience predictions, followed by teacher support and emotional regulation. Higher levels of all three predictors were consistently

associated with increased predicted resilience scores. The findings demonstrate that academic resilience among gifted students with twice-exceptional profiles is strongly influenced by a combination of cognitive, emotional, and contextual factors. Metacognitive awareness emerged as the most powerful predictor, highlighting the importance of self-regulated learning processes in facilitating adaptive academic functioning. Perceived teacher support and emotional regulation also made substantial contributions, underscoring the critical roles of supportive educational relationships and emotional competencies. The results suggest that interventions designed to strengthen metacognitive skills, enhance emotional regulation, and foster supportive teacher-student interactions may effectively promote resilience and educational success among twice-exceptional learners.

**Keywords:** *academic resilience; twice-exceptional students; gifted education; metacognitive awareness; emotional regulation; perceived teacher support*

## 1. Introduction

Academic resilience has emerged as one of the most important constructs in contemporary educational psychology because it explains why some students are able to maintain high levels of academic engagement, motivation, and achievement despite experiencing significant personal, social, or educational challenges. Academic resilience refers to the capacity to effectively adapt to academic adversity, recover from setbacks, persist in the face of difficulties, and continue striving toward educational goals despite obstacles. Increasingly complex educational environments, heightened academic expectations, rapid technological transformation, and growing concerns regarding student well-being have intensified scholarly interest in the mechanisms that promote resilience among diverse student populations. Recent research has demonstrated that resilient learners exhibit stronger self-regulatory capacities, greater perseverance, more adaptive coping strategies, and higher academic achievement than their less resilient peers. Moreover, resilience has been identified as a crucial protective factor that supports long-term educational success and psychological well-being across developmental stages (Ayasrah et al., 2025; Lai, 2025; Ragusa et al., 2023). As educational systems increasingly emphasize not only academic excellence but also holistic development, understanding the factors that contribute to resilience has become an important priority for researchers, educators, and policymakers.

The importance of academic resilience becomes particularly evident when examining gifted students with twice-exceptional profiles. Twice-exceptional students are individuals who simultaneously demonstrate outstanding intellectual abilities or giftedness while also experiencing one or more disabilities, such as specific learning disabilities, attention-deficit/hyperactivity disorder, autism spectrum disorder, or emotional and behavioral disorders.

Although gifted students are frequently assumed to possess educational advantages, research increasingly suggests that twice-exceptional learners face unique challenges that may compromise their academic performance, emotional adjustment, and school engagement. These students often encounter discrepancies between their cognitive potential and academic outcomes, leading to frustration, diminished self-confidence, and increased vulnerability to underachievement. Furthermore, educational systems frequently struggle to identify and adequately support both the strengths and challenges of twice-exceptional learners, resulting in unmet educational needs and reduced opportunities for talent development. A growing body of literature has highlighted that the educational experiences of gifted students cannot be fully understood solely through measures of intelligence or achievement; instead, psychosocial and environmental factors play critical roles in determining academic success and adaptation (Choi & Kaufman, 2025; Desmet et al., 2025; Raouf et al., 2024). Consequently, identifying the factors that promote resilience among twice-exceptional students represents an important avenue for advancing both gifted education and inclusive educational practices.

Recent investigations into gifted education have challenged traditional assumptions that giftedness automatically guarantees educational success. Contemporary scholars argue that gifted learners frequently experience complex emotional, social, and motivational difficulties that require intentional support and intervention. Choi and Kaufman emphasized the ongoing tension between excellence and inclusion in gifted education, arguing that educational systems must move beyond achievement-focused perspectives and recognize the diverse developmental needs of gifted students (Choi & Kaufman, 2025). Similarly, Elias and colleagues contended that the social-emotional competencies of gifted children should be

deliberately cultivated within inclusive educational environments because cognitive strengths alone are insufficient to ensure positive developmental outcomes (Elias et al., 2024). Research has also demonstrated that gifted students who experience chronic stress or insufficient emotional support may encounter significant barriers to achievement and psychological well-being. For example, investigations examining stress management among gifted children have shown that effective coping and emotional adjustment contribute not only to student functioning but also to broader family well-being outcomes (Zanetti et al., 2024). These findings collectively suggest that resilience may serve as a critical mechanism through which gifted students successfully navigate the challenges associated with twice-exceptionality.

Among the various factors associated with academic resilience, metacognitive awareness has received substantial scholarly attention. Metacognition refers to individuals' awareness, monitoring, and regulation of their own cognitive processes. Students with strong metacognitive skills are better able to plan learning activities, evaluate progress, adapt strategies, monitor comprehension, and regulate effort during challenging academic tasks. Such capacities are particularly valuable for twice-exceptional learners who frequently encounter discrepancies between intellectual potential and academic performance. Recent empirical studies have consistently identified metacognition as a significant predictor of resilience, adaptive learning behaviors, and academic success. Turgut and Uğurlu demonstrated that metacognitive processes were strongly associated with mathematical resilience among gifted students, suggesting that students who effectively regulate their thinking are more capable of overcoming academic challenges and maintaining persistence during difficult learning experiences (Turgut & Uğurlu, 2024). Similarly, Zhou and Hou reported that metacognition contributes significantly to engagement and adaptive functioning by enhancing self-efficacy and goal-directed behavior (Zhou & Hou, 2025). Additional evidence indicates that metacognitive knowledge supports openness, adaptive emotional responses, and professional effectiveness across educational contexts (Guo, 2025). Systematic reviews have further suggested that metacognitive competencies represent foundational meta-skills that support motivation, emotional intelligence, and psychological well-being across diverse populations (Mitsea et al., 2024). Collectively, these findings indicate that metacognitive awareness may function as a central determinant of resilience among twice-

exceptional students by enabling them to effectively navigate complex academic demands.

Another important contributor to academic resilience is emotional regulation. Emotional regulation refers to the processes through which individuals monitor, evaluate, and modify emotional experiences and expressions in order to achieve personal goals and adapt to environmental demands. Effective emotional regulation enables students to manage stress, cope with frustration, maintain motivation, and respond constructively to academic setbacks. For twice-exceptional students, who often encounter challenges related to perfectionism, asynchronous development, social isolation, or disability-related frustrations, emotional regulation may be particularly critical. Research has consistently demonstrated that emotional competencies support both academic performance and psychological adjustment. Jennings and colleagues emphasized that emotional schemas constitute essential components of educators' and students' social-emotional competencies, influencing learning, engagement, and well-being outcomes (Jennings et al., 2024). Likewise, systematic reviews of school-based interventions have shown that programs focused on mentalization and socio-emotional development can significantly enhance students' emotional competencies and adaptive behaviors (Chelouche-Dwek & Fonagy, 2024). Evidence from positive psychology and technology-assisted interventions further suggests that emotional intelligence and emotional regulation skills contribute substantially to resilience, motivation, and overall well-being (Mitsea et al., 2024). Therefore, emotional regulation may represent an important mechanism through which twice-exceptional students maintain academic resilience despite experiencing educational or psychological challenges.

Beyond individual psychological characteristics, environmental and relational factors also play a crucial role in fostering academic resilience. Among these factors, perceived teacher support has consistently emerged as one of the most influential predictors of positive educational outcomes. Teacher support encompasses students' perceptions that teachers are available, caring, encouraging, responsive, and invested in their academic and personal development. Supportive teacher-student relationships create learning environments that promote confidence, engagement, and persistence. Research has shown that teacher support contributes significantly to self-regulated learning, motivation, and resilience across various educational contexts. Xie found that supportive teacher behaviors were directly associated with greater learner

resilience and more effective self-regulated learning strategies among students facing educational challenges (Xie, 2024). Similarly, investigations conducted in socially disadvantaged educational settings revealed that supportive school environments can enhance student engagement and academic persistence even under adverse conditions (Obrovská et al., 2024). The importance of teacher support is particularly relevant for twice-exceptional students because these learners often require educators who can simultaneously recognize their strengths and accommodate their disabilities. Consequently, perceived teacher support may function as a critical contextual resource that facilitates resilience and academic adaptation.

The growing emphasis on self-regulated learning and learner autonomy has further reinforced interest in the mechanisms underlying resilience. Studies have demonstrated that self-regulation, adaptive learning strategies, and reflective assessment practices contribute substantially to students' capacity to cope with academic demands and persist in challenging circumstances. Ragusa and colleagues reported that stronger academic self-regulation was associated with lower levels of procrastination, reduced academic stress and anxiety, enhanced resilience, and improved academic performance among secondary school students (Ragusa et al., 2023). Similarly, research examining formative assessment practices has shown that opportunities for self-assessment and peer assessment can strengthen learners' metacognitive engagement and educational effectiveness (Parmigiani, 2025). Investigations focusing on learning strategies have further demonstrated that psychological well-being positively influences strategic learning behaviors and educational adaptation (Suting & Veloo, 2024). Studies examining mindfulness-based interventions have also reported improvements in concentration and academic functioning through enhanced self-awareness and attentional regulation (Gallardo & Luna, 2024). Together, these findings underscore the interconnected nature of metacognition, emotional functioning, and resilience within educational contexts.

Technological innovations have also expanded understanding of resilience development in contemporary educational settings. Advances in artificial intelligence, educational technologies, and blended learning environments have created new opportunities to support student adaptation and learning. For example, AI-assisted educational approaches have been linked to improvements in both academic efficacy and resilience, suggesting that

technology can facilitate adaptive learning processes when appropriately implemented (Lai, 2025). Similarly, the development of innovative resilience assessment tools has enabled researchers to examine resilience through increasingly sophisticated conceptual and methodological frameworks. The AI-Integrated Metacognitive Learning Resilience Scale developed by Ayasrah and colleagues reflects the growing recognition that resilience and metacognition are closely interconnected constructs within modern educational systems (Ayasrah et al., 2025). These developments suggest that resilience should be understood not merely as a stable personality trait but rather as a dynamic process shaped by interactions among cognitive, emotional, social, and contextual factors.

Although the existing literature has identified important relationships among resilience, metacognition, emotional functioning, and educational support, several significant gaps remain. First, much of the available research has focused on general student populations, leaving comparatively limited evidence regarding gifted students with twice-exceptional profiles. Second, previous investigations have frequently relied on traditional statistical techniques that may not adequately capture the complex, nonlinear relationships among psychological and contextual variables. Educational outcomes are often influenced by multidimensional interactions that cannot be fully explained through linear modeling approaches. Machine learning methods provide powerful alternatives capable of identifying intricate predictive patterns and estimating the relative importance of multiple contributing factors simultaneously. Third, despite growing evidence supporting the roles of metacognition, emotional regulation, and teacher support individually, few studies have examined their combined contributions to academic resilience within a unified predictive framework specifically targeting twice-exceptional gifted learners. Addressing these limitations is particularly important because resilience may represent a key mechanism through which gifted students overcome underachievement, maintain engagement, and achieve their full potential (Clark et al., 2024; Desmet et al., 2025; Raouf et al., 2024).

In light of these theoretical and empirical considerations, the present study aimed to examine the predictive contributions of metacognitive awareness, emotional regulation, and perceived teacher support to academic resilience among gifted students with twice-exceptional profiles using a Light Gradient Boosting Machine (LightGBM) model.

## 2. Methods and Materials

### 2.1. Study Design and Participants

The present study employed a cross-sectional, predictive correlational design to examine the extent to which metacognitive awareness, emotional regulation, and perceived teacher support predict academic resilience among gifted students with twice-exceptional (2e) profiles. Twice-exceptional students are those who simultaneously demonstrate high intellectual or gifted potential and one or more diagnosed learning, behavioral, emotional, or developmental disabilities. The study was conducted in Canada during the 2025–2026 academic year. Participants were recruited from specialized gifted education programs, inclusive educational settings, and support centers serving students with exceptional learning needs across the provinces of Ontario, British Columbia, and Alberta. A total of 428 gifted students with documented twice-exceptional profiles participated in the study. Participants ranged in age from 12 to 18 years and were enrolled in middle and secondary schools. Eligibility criteria included formal identification as gifted by educational authorities and documentation of at least one coexisting exceptionality, such as a specific learning disability, attention-deficit/hyperactivity disorder, autism spectrum disorder, or emotional-behavioral disorder. Stratified random sampling procedures were used to ensure adequate representation across age groups, gender, and educational settings. Participation was voluntary, and informed consent was obtained from parents or legal guardians as well as assent from student participants.

### 2.2. Measures

Data were collected using a battery of standardized instruments with established psychometric properties. Academic resilience was assessed using the Academic Resilience Scale (ARS-30) developed by Cassidy (2016). The ARS-30 is a widely used self-report measure designed to evaluate students' capacity to effectively cope with academic setbacks, challenges, and pressures. The instrument consists of 30 items rated on a five-point Likert scale ranging from strongly disagree to strongly agree. The scale assesses adaptive persistence, emotional responses to academic adversity, and problem-focused coping strategies. Higher scores indicate greater academic resilience. Previous studies conducted across diverse educational contexts have reported strong internal consistency coefficients, typically

exceeding 0.85, as well as satisfactory construct and criterion validity. The scale has demonstrated particular utility in studies involving academically talented and high-achieving student populations.

Metacognitive awareness was measured using the Metacognitive Awareness Inventory (MAI) developed by Schraw and Dennison (1994). The MAI contains 52 items designed to assess individuals' awareness and regulation of cognitive processes during learning and problem solving. The instrument comprises two major dimensions: knowledge of cognition and regulation of cognition. Knowledge of cognition includes declarative, procedural, and conditional knowledge, whereas regulation of cognition encompasses planning, information management strategies, monitoring, debugging strategies, and evaluation. Responses are provided on a Likert-type scale, with higher scores reflecting greater metacognitive awareness. Numerous studies have confirmed the inventory's strong psychometric characteristics, including high internal consistency, factorial validity, and predictive validity across adolescent and gifted student populations.

Emotional regulation was assessed using the Emotion Regulation Questionnaire (ERQ) developed by Gross and John (2003). The ERQ consists of 10 items measuring two central emotion regulation strategies: cognitive reappraisal and expressive suppression. Participants indicate their agreement with each statement using a seven-point Likert scale ranging from strongly disagree to strongly agree. Higher scores indicate greater use of the respective emotion regulation strategy. The ERQ has been extensively validated across adolescent and educational populations and has demonstrated satisfactory reliability, convergent validity, and cross-cultural applicability. Given the importance of emotional self-management in promoting resilience among twice-exceptional learners, the ERQ was selected as an appropriate measure for assessing individual differences in emotional regulation processes.

Perceived teacher support was measured using the Teacher Support Scale developed by Torsheim et al. (2000). This instrument evaluates students' perceptions of emotional, academic, and interpersonal support received from teachers within the school environment. The scale contains items assessing teacher accessibility, encouragement, fairness, responsiveness, and instructional assistance. Responses are recorded using a five-point Likert scale, with higher scores indicating stronger perceptions of teacher support. Previous research has consistently demonstrated acceptable levels of internal consistency and

construct validity and has identified perceived teacher support as an important predictor of positive academic and psychological outcomes among students with diverse educational needs. The scale has been successfully applied in studies examining resilience, school adjustment, and academic achievement among adolescents.

### 2.3. Data Analysis

Data analysis was conducted using Python 3.11 and R statistical software. Preliminary analyses included data screening for missing values, outliers, normality, and multicollinearity. Descriptive statistics, including means, standard deviations, skewness, and kurtosis indices, were calculated for all study variables. Pearson correlation coefficients were computed to examine bivariate relationships among academic resilience, metacognitive awareness, emotional regulation, and perceived teacher support. To investigate the predictive contributions of the independent variables, a Light Gradient Boosting Machine (LightGBM) model was developed using academic resilience scores as the target variable. The dataset was randomly divided into training (80%) and testing (20%) subsets. Hyperparameter optimization was performed using five-fold cross-validation combined with grid-search procedures to identify the optimal model configuration. Model performance was evaluated using the coefficient of determination ( $R^2$ ), root mean square error (RMSE), mean absolute error (MAE), and mean absolute percentage error (MAPE). Feature importance analysis was conducted to determine the relative contribution of each predictor to

academic resilience. In addition, SHAP (Shapley Additive Explanations) values were calculated to provide interpretable estimates of the direction and magnitude of predictor effects, thereby enhancing the transparency and explanatory power of the LightGBM model. Statistical significance was evaluated at the 0.05 level for conventional analyses, while machine learning performance metrics were interpreted according to established predictive modeling standards.

### 3. Findings and Results

A total of 428 gifted students with twice-exceptional profiles participated in the study. The sample consisted of 231 males (54.0%) and 197 females (46.0%). Participants ranged in age from 12 to 18 years, with a mean age of 15.12 years ( $SD = 1.74$ ). Regarding educational level, 182 students (42.5%) were enrolled in middle school and 246 students (57.5%) were enrolled in secondary school. In terms of exceptionality profiles, 156 students (36.4%) had a specific learning disability, 128 students (29.9%) had attention-deficit/hyperactivity disorder, 79 students (18.5%) had autism spectrum disorder, and 65 students (15.2%) had emotional-behavioral disorders. Missing data represented less than 2% of all responses and were handled using multiple imputation procedures prior to analysis. Preliminary screening indicated no significant violations of normality assumptions, and all variables demonstrated acceptable distributions for subsequent statistical and machine-learning analyses.

**Table 1**

*Descriptive Statistics and Correlations Among Study Variables*

Variable	Mean	SD	1	2	3	4
1. Academic Resilience	108.74	16.82	—			
2. Metacognitive Awareness	187.65	24.17	.71**	—		
3. Emotional Regulation	47.91	8.26	.58**	.49**	—	
4. Perceived Teacher Support	39.82	7.45	.63**	.54**	.42**	—

Table 1 presents the descriptive statistics and Pearson correlation coefficients for all study variables. Academic resilience demonstrated a mean score of 108.74 ( $SD = 16.82$ ), indicating moderate to high levels of resilience among the participating twice-exceptional students. Metacognitive awareness exhibited the highest mean value among the predictor variables ( $M = 187.65$ ,  $SD = 24.17$ ), while emotional regulation ( $M = 47.91$ ,  $SD = 8.26$ ) and perceived teacher support ( $M = 39.82$ ,  $SD = 7.45$ ) also

showed substantial variability. Significant positive correlations were observed among all variables. Academic resilience was most strongly associated with metacognitive awareness ( $r = .71$ ,  $p < .01$ ), followed by perceived teacher support ( $r = .63$ ,  $p < .01$ ) and emotional regulation ( $r = .58$ ,  $p < .01$ ). These findings provide preliminary evidence that students demonstrating stronger metacognitive skills, more effective emotional regulation, and higher perceptions of teacher support tend to exhibit greater academic resilience.

**Table 2**

*Performance Metrics of the LightGBM Model Predicting Academic Resilience*

Metric	Training Set	Testing Set
R <sup>2</sup>	0.892	0.847
RMSE	5.71	6.84
MAE	4.39	5.18
MAPE (%)	4.26	5.03

The predictive performance of the LightGBM model is presented in Table 2. The model demonstrated excellent predictive accuracy across both the training and testing datasets. Specifically, the model explained 84.7% of the variance in academic resilience scores within the testing dataset ( $R^2 = .847$ ), indicating strong generalizability and minimal overfitting. The RMSE value of 6.84 and MAE value of 5.18 suggest that prediction errors remained relatively small compared to the observed variability in

resilience scores. Furthermore, the MAPE value of 5.03% indicates a high degree of precision in forecasting academic resilience. The close correspondence between training and testing performance metrics provides evidence that the LightGBM model effectively captured the underlying relationships between metacognitive awareness, emotional regulation, perceived teacher support, and academic resilience among twice-exceptional gifted students.

**Table 3**

*Feature Importance Analysis from the LightGBM Model*

Predictor	Gain Importance (%)	Split Importance (%)
Metacognitive Awareness	43.82	39.67
Perceived Teacher Support	33.76	35.18
Emotional Regulation	22.42	25.15

The feature importance results presented in Table 3 indicate that metacognitive awareness emerged as the most influential predictor of academic resilience. According to gain-based importance values, metacognitive awareness accounted for 43.82% of the total predictive contribution within the model, substantially exceeding the contributions of perceived teacher support (33.76%) and emotional regulation (22.42%). Similar patterns were observed for split importance values, which measure the frequency with which

variables contribute to decision-tree construction. These findings suggest that the capacity to monitor, regulate, and evaluate one's own cognitive processes represents the strongest determinant of resilience in academically gifted students with twice-exceptional profiles. Nevertheless, both perceived teacher support and emotional regulation also demonstrated meaningful contributions, highlighting the importance of environmental and emotional factors in fostering academic adaptation and persistence.

**Table 4**

*SHAP-Based Global Predictor Effects on Academic Resilience*

Predictor	Mean Absolute SHAP Value	Rank
Metacognitive Awareness	12.48	1
Perceived Teacher Support	9.71	2
Emotional Regulation	6.92	3

Table 4 reports the SHAP-based global interpretation results. Consistent with the feature importance analysis, metacognitive awareness achieved the highest mean absolute SHAP value (12.48), indicating the strongest average impact on academic resilience predictions across all

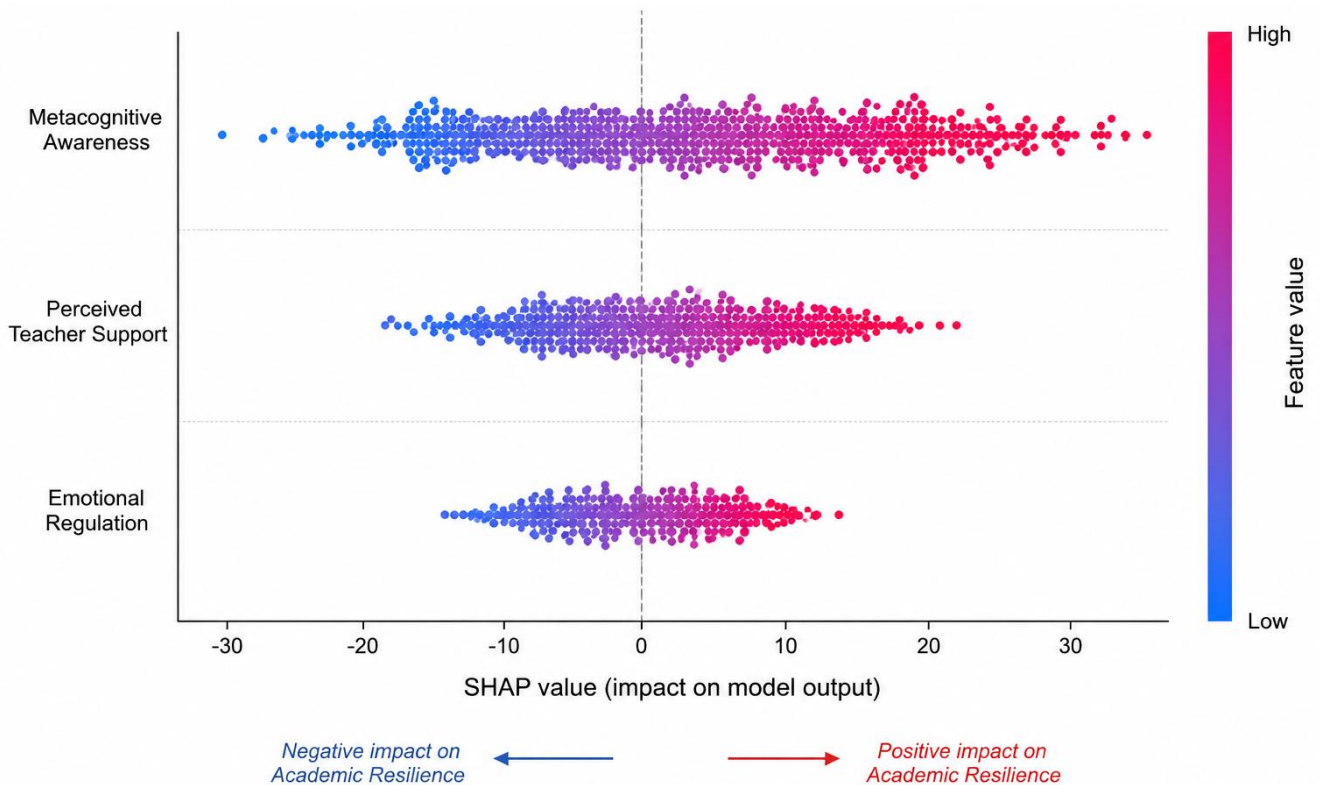
participants. Perceived teacher support ranked second (9.71), while emotional regulation ranked third (6.92). The SHAP analysis further revealed that higher levels of each predictor were generally associated with positive contributions to predicted academic resilience scores.

Students reporting stronger metacognitive awareness, more supportive teacher relationships, and more adaptive emotional regulation strategies tended to receive substantially higher resilience predictions from the model. These findings confirm the robustness of the predictor

rankings obtained from the LightGBM feature importance analysis and provide interpretable evidence regarding the direction and magnitude of predictor effects.

**Figure 1**

*SHAP Summary Plot Illustrating the Relative Contributions of Metacognitive Awareness, Perceived Teacher Support, and Emotional Regulation to Academic Resilience Predictions*



The SHAP summary plot demonstrated clear differentiation in the predictive influence of the three variables included in the model. Metacognitive awareness displayed the widest distribution of SHAP values, indicating substantial variability in its influence across participants and confirming its dominant role in resilience prediction. Perceived teacher support exhibited the second-largest distribution, suggesting that supportive educational environments consistently enhanced resilience outcomes. Emotional regulation demonstrated a comparatively narrower distribution of SHAP values but remained positively associated with resilience predictions across most observations. The visualization further showed that higher values of all three predictors were associated with positive SHAP values, reflecting increased predicted academic resilience. Conversely, lower predictor values tended to

produce negative SHAP values, indicating reduced resilience predictions. Collectively, the SHAP visualization supports the conclusion that academic resilience among gifted students with twice-exceptional profiles is shaped by a combination of cognitive self-regulation processes, emotional management capacities, and supportive teacher–student relationships, with metacognitive awareness emerging as the most influential factor within the predictive framework.

**4. Discussion**

The present study examined the contributions of metacognitive awareness, emotional regulation, and perceived teacher support to academic resilience among gifted students with twice-exceptional profiles using a Light

Gradient Boosting Machine (LightGBM) model. The findings revealed that the machine learning model demonstrated a high level of predictive accuracy, explaining approximately 85% of the variance in academic resilience scores. Furthermore, metacognitive awareness emerged as the strongest predictor of academic resilience, followed by perceived teacher support and emotional regulation. Correlational analyses also demonstrated significant positive relationships among all study variables, indicating that students who reported stronger metacognitive skills, more adaptive emotional regulation, and greater teacher support tended to exhibit higher levels of academic resilience. These findings contribute to the growing body of literature emphasizing the multidimensional nature of resilience and provide important insights into the mechanisms that facilitate successful adaptation among twice-exceptional learners.

One of the most important findings of the study was the dominant role of metacognitive awareness in predicting academic resilience. Both the LightGBM feature importance analysis and SHAP interpretation results identified metacognitive awareness as the most influential variable in the model. This finding is theoretically consistent with self-regulated learning frameworks, which suggest that students who actively monitor, evaluate, and regulate their cognitive processes are better equipped to respond effectively to academic challenges. Twice-exceptional students often encounter discrepancies between their intellectual strengths and disability-related difficulties. Consequently, the ability to strategically plan learning activities, monitor comprehension, adjust approaches to problem solving, and evaluate performance may be especially important for maintaining persistence and overcoming obstacles. Students possessing strong metacognitive skills are more likely to interpret setbacks as manageable challenges rather than indicators of failure, thereby strengthening resilience in demanding academic environments.

The current findings align closely with previous research highlighting the central role of metacognition in educational adaptation and resilience. Turgut and Uğurlu demonstrated that metacognition significantly contributes to mathematical resilience among gifted students and serves as a mechanism through which learners cope with academic difficulty and uncertainty (Turgut & Uğurlu, 2024). Similarly, Zhou and Hou reported that metacognition promotes adaptive functioning through its positive influence on self-efficacy, persistence, and engagement (Zhou & Hou, 2025). Research conducted by Guo further suggested that metacognitive

knowledge contributes to adaptive emotional responses and effective educational functioning by facilitating self-reflective learning processes (Guo, 2025). Moreover, Ayasrah and colleagues emphasized the close conceptual relationship between metacognition and learning resilience through the development and validation of an AI-integrated resilience measure that explicitly incorporates metacognitive dimensions (Ayasrah et al., 2025). The convergence between these studies and the present findings strengthens the argument that metacognition represents a foundational psychological resource that enables twice-exceptional students to transform cognitive strengths into resilient academic behavior.

The results also demonstrated that perceived teacher support was the second most influential predictor of academic resilience. Students who perceived their teachers as supportive, responsive, encouraging, and understanding reported substantially higher levels of resilience. This finding underscores the importance of environmental and relational factors in promoting positive academic outcomes among gifted learners with disabilities. Twice-exceptional students frequently experience educational challenges that may not be fully recognized by teachers or school systems. When teachers acknowledge both gifted potential and disability-related needs, students are more likely to develop confidence, engagement, and persistence. Supportive teacher-student relationships may provide emotional security, academic guidance, and motivational reinforcement that help students navigate adversity while maintaining educational aspirations.

The observed association between teacher support and resilience is highly consistent with previous literature. Xie found that teacher support directly contributes to learner resilience through its positive influence on self-regulated learning and adaptive coping strategies (Xie, 2024). Likewise, Obrovská and colleagues demonstrated that educational support systems promote engagement and persistence among students facing socioeconomic and educational disadvantages (Obrovská et al., 2024). Although the context of their study differed from the present investigation, the underlying mechanism appears similar: supportive educational relationships provide resources that enable students to overcome barriers and sustain academic participation. Furthermore, Elias and colleagues argued that gifted students require intentionally supportive educational environments that foster not only academic achievement but also social-emotional development (Elias et al., 2024). Choi and Kaufman similarly emphasized the need for educational

systems that balance excellence with inclusion, suggesting that meaningful teacher support is essential for meeting the diverse needs of gifted populations (Choi & Kaufman, 2025). The present findings extend this literature by demonstrating that teacher support remains a powerful determinant of resilience even when sophisticated machine learning models simultaneously consider multiple psychological factors.

Emotional regulation also emerged as a significant predictor of academic resilience, although its contribution was smaller than those of metacognitive awareness and teacher support. This finding nevertheless highlights the critical role of emotional processes in educational adaptation. Twice-exceptional students frequently experience frustration, anxiety, perfectionistic concerns, social difficulties, and emotional stress resulting from the coexistence of high ability and disability-related challenges. Effective emotional regulation enables these students to manage negative emotions, maintain motivation, recover from setbacks, and sustain goal-directed behavior. Students who successfully regulate emotional responses may be less likely to disengage from learning following academic difficulties and more likely to employ adaptive coping strategies that facilitate resilience.

The current findings support and extend existing research regarding the relationship between emotional competencies and resilience. Jennings and colleagues proposed that emotional schemas represent fundamental components of social-emotional competence that influence educational functioning and psychological adjustment (Jennings et al., 2024). Similarly, Chelouche-Dwek and Fonagy concluded that interventions targeting socio-emotional competencies can enhance positive behaviors and adaptive functioning among students (Chelouche-Dwek & Fonagy, 2024). Systematic review evidence further suggests that emotional intelligence and emotional regulation contribute substantially to well-being, motivation, and resilience across diverse populations (Mitsea et al., 2024). These findings collectively support the interpretation that emotional regulation functions as a protective resource that helps twice-exceptional students maintain positive academic functioning despite exposure to stressors and challenges.

The strong correlations observed among metacognitive awareness, emotional regulation, teacher support, and academic resilience further support contemporary theoretical perspectives emphasizing the interconnected nature of cognitive, emotional, and contextual factors. Rather than operating independently, these variables likely

interact dynamically to influence resilience outcomes. Metacognitive awareness may facilitate resilience partly by improving emotional regulation and enabling more effective responses to challenges. Similarly, supportive teachers may strengthen students' metacognitive engagement and emotional adjustment through instructional guidance and positive interpersonal interactions. This interpretation is consistent with broader self-regulated learning theories suggesting that successful academic adaptation emerges from coordinated interactions among cognitive strategies, motivational processes, emotional competencies, and environmental supports (Parmigiani, 2025; Ragusa et al., 2023).

The present findings also contribute to the literature on gifted underachievement and twice-exceptionality. Previous reviews have identified both internal and external factors as contributors to underachievement among gifted students (Raouf et al., 2024). Internal factors include motivational difficulties, emotional challenges, and self-regulatory weaknesses, whereas external factors include insufficient educational support and inappropriate instructional practices. The current study suggests that metacognitive awareness, emotional regulation, and teacher support collectively address several of these risk factors by enhancing students' capacity to manage learning demands and respond adaptively to adversity. Consequently, resilience may represent an important pathway through which gifted students avoid underachievement and achieve outcomes that more accurately reflect their intellectual potential.

Another notable contribution of the study concerns its methodological approach. Educational research examining resilience has traditionally relied on linear statistical models that assume relatively simple relationships among variables. However, psychological and educational phenomena are often characterized by nonlinear interactions and complex dependencies. The high predictive accuracy achieved by the LightGBM model suggests that machine learning approaches may provide valuable tools for understanding resilience among diverse student populations. The use of SHAP analyses further enhanced interpretability by identifying the relative contributions of individual predictors. These methodological advantages support growing interest in applying advanced analytical techniques to educational and psychological research. Similar technological and data-driven innovations have recently been highlighted as promising avenues for enhancing

learning, assessment, and resilience development in educational settings (Lai, 2025).

The findings also have implications for positive psychology perspectives on education. Positive psychology emphasizes the cultivation of strengths, competencies, and protective factors rather than focusing exclusively on deficits or pathology. Metacognitive awareness, emotional regulation, and supportive teacher relationships can all be conceptualized as developmental assets that contribute to positive adaptation. Previous research has demonstrated that psychological well-being supports effective learning strategies and educational engagement (Suting & Veloo, 2024), while mindfulness and self-awareness interventions enhance concentration and academic functioning (Gallardo & Luna, 2024). Likewise, resilience has been linked to positive academic outcomes, reduced stress, and improved educational adjustment (Ragusa et al., 2023). The present study reinforces these perspectives by identifying specific strengths and resources that may promote resilience among twice-exceptional learners.

## 5. Conclusion

The findings may also be interpreted within broader developmental frameworks emphasizing adaptation in the face of adversity. Clark and colleagues demonstrated that positive growth processes can emerge from challenging experiences when individuals possess adequate psychological resources and supportive environments (Clark et al., 2024). Similarly, research on achievement motivation interventions among gifted students suggests that targeted supports can help resolve underachievement and facilitate positive educational outcomes (Desmet et al., 2025). The present study extends these perspectives by suggesting that resilience among twice-exceptional students is influenced by a combination of cognitive, emotional, and relational resources that collectively support adaptive development despite ongoing challenges.

The study has several limitations that should be acknowledged. First, the cross-sectional design limits the ability to draw causal conclusions regarding the relationships among the study variables. Second, all measures relied on student self-report data, creating the possibility of social desirability bias and common method variance. Third, although the sample included students from multiple Canadian provinces, the findings may not generalize to other cultural, educational, or policy contexts. Fourth, the study focused on three predictors of resilience

and did not examine other potentially influential variables such as family support, peer relationships, motivation, executive functioning, socioeconomic status, or school climate. Finally, although machine learning models provide strong predictive performance, they do not fully explain the developmental mechanisms through which resilience emerges over time.

Future research should employ longitudinal designs to examine the developmental trajectories of resilience among twice-exceptional learners and identify causal pathways linking metacognition, emotional regulation, teacher support, and academic outcomes. Researchers may also investigate additional protective factors, including parental involvement, peer support, self-efficacy, achievement motivation, executive functioning, and school connectedness. Comparative studies involving different categories of twice-exceptionality could provide greater insight into whether resilience mechanisms vary across disability profiles. Furthermore, intervention studies are needed to determine whether targeted programs designed to strengthen metacognitive awareness, emotional regulation, and teacher support can produce meaningful improvements in resilience and academic success. Future studies may also benefit from integrating qualitative methodologies and advanced machine learning techniques to develop more comprehensive models of resilience.

From a practical perspective, the findings suggest that educational professionals should prioritize the development of metacognitive skills, emotional competencies, and supportive teacher-student relationships when working with gifted students who have twice-exceptional profiles. Schools should provide explicit instruction in self-regulated learning strategies, reflective thinking, planning, monitoring, and evaluation skills. Social-emotional learning programs should be incorporated into gifted education services to strengthen emotional regulation and coping capacities. Professional development initiatives can help teachers recognize the unique strengths and challenges of twice-exceptional students and develop supportive instructional practices that foster resilience. Educational policies should encourage inclusive learning environments that simultaneously nurture gifted potential and address disability-related needs. Through coordinated efforts targeting cognitive, emotional, and relational dimensions of development, schools can create conditions that enable twice-exceptional learners to thrive academically and personally.

## Authors' Contributions

Authors equally contributed to this article.

## Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

## Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

## Acknowledgments

We would like to express our gratitude to all individuals helped us to do the project.

## Declaration of Interest

The authors report no conflict of interest.

## Funding

According to the authors, this article has no financial support.

## Ethics Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

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